The Cycle of Technology Disruption: Analog Devices' MACSYM

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December 15, 2000
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1. Introduction

By the 1970’s Analog Devices’, a Massachusetts based high technology company, had become a leading analog components manufacturer. Yet, Analog Devices Inc. (ADI) led by founder and president, Raymond Stata, desired to expand its product line to enter new and emerging markets.

This desire formed the basis for several explorations into new markets and technologies. By 1973, these efforts had resulted in the formation of the Systems Development Group (SDG) charged with creating a revolutionary measurement and control machine that was cheaper and simpler than existing products in the market. The group carried with it the hope of not only developing this innovative technology but also vastly expanding Analog Devices’ business. The concept of a control system materialized into the Measurement And Control SYsteM, MACSYM, a desktop computer specialized for measurement and control. By 1978, the first commercial MACSYM product, MACSYM II, was released to the general public.

The product was well received with orders from customers exceeding ADI’s expectations. ADI anticipated that the MACSYM product line would grow as large as its entire existing product line\(^1\). Yet, despite the initial excitement surrounding the product, MACSYM’s success was short lived. By 1985 MACSYM was no longer mentioned in ADI literature, and by 1989, the product line was discontinued.\(^2\)

How did this promising technology move from success to failure so quickly in the marketplace? Research indicates that MACSYM’s failure was not a result of engineering incompetence. In fact, evaluating MACSYM using technical criteria presents the system as a significant technological achievement.

Table 1 – ADI 1980 Fiscal Year Statistics\(^3\)

<table>
<thead>
<tr>
<th>ADI statistics for fiscal year ended November 1, 1980:</th>
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<tbody>
<tr>
<td>Net sales</td>
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<tr>
<td>Gross margin</td>
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<tr>
<td>Operating income</td>
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<tr>
<td>Net income</td>
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<td>Persons employed</td>
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\(^1\) 1980 Annual Report, p6
\(^2\) http://www.analog.com/industry/ios/ios_faq.html
\(^3\) Securities and Exchange Commission, Form 10-K for Analog Devices, Inc., 1980
Yet, examining MACSYM as a product of a business intended to generate profit clearly shows the system’s failure. This paper explores the history of MACSYM and applies a theoretical framework to propose an explanation for the technology’s short-lived success.

2. Framework of Analysis– Disruptive Technology

The reasons for MACSYM’s failure could be best explained by the concept of disruptive technologies, as described in Clayton Christensen’s book, The Innovator’s Dilemma. A disruptive technology is a technology that emerges unforeseen into a market, causes fundamental changes to the market, and often usurps the position of the previous mainstream companies.

We consolidate Christensen’s ideas into a simple, comprehensible cycle that demonstrates the life of a disrupted technology. This interaction is described herein as the Cycle of Technology Disruption and consists of three distinct phases termed as: sustaining technology, rise of the disruptive technology, and the disruption. This cycle characterizes technologies that rise and fall in competition–MACSYM’s history is no exception. The section below provides a brief overview of Christensen’s model of disruptive technology and proceeds to explain the Cycle of Technology Disruption, which provides the basis of analysis for this paper.

2.1. Christensen’s Model

Every technology company has a set of characteristics or dimensions along which it aims to improve. These dimensions are what it believes best fit its value network, a term coined by Christensen to encapsulate “the context within which a firm identifies and responds to customers’ needs, solves problems, procures input, reacts to competitors, and strives for profit.”

In Christensen’s framework, a sustaining technology is a technology that “improve[s] performance of established products, along the dimensions of performance that mainstream customers in major markets have historically valued.” A disruptive technology is one that has lower performance than the sustaining technology along the mainstream dimensions, but succeeds in a different market because it performs well along a different dimension. It is usually cheaper than the sustaining technology, so it begins in a new, emerging market. As the disruptive technology incubates in the new market, it eventually reaches the performance demand along the sustaining technology’s mainstream market dimensions and replaces the sustaining technology.

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4 Christensen, Innovator’s Dilemma, p.32.
5 Christensen, Innovator’s Dilemma p. xv.
Table 2 - Examples of Disruptive Technology\(^7\)

<table>
<thead>
<tr>
<th>Established Technology</th>
<th>Disruptive Technology</th>
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<tbody>
<tr>
<td>Silver halide photographic film</td>
<td>Digital photography</td>
</tr>
<tr>
<td>Wireline telephony</td>
<td>Mobile telephony</td>
</tr>
<tr>
<td>Notebook computers</td>
<td>Hand-held digital appliances</td>
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<tr>
<td>Bricks and mortar retailing</td>
<td>On-line retailing</td>
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<tr>
<td>Industrial materials distributors</td>
<td>Internet-based sites such as Chemdex and E-steel</td>
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<tr>
<td>Electric utility companies</td>
<td>Distributed power generation (gas turbines, micro-turbines, fuel cells)</td>
</tr>
<tr>
<td>Manned fighter and bomber aircraft</td>
<td>Unmanned aircraft</td>
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<tr>
<td>Open surgery</td>
<td>Arthroscopic and endoscopic surgery</td>
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</tbody>
</table>

2.2. Cycle of Technology Disruption

Christensen, in his analysis, goes into extensive detail explaining the principles which drive the movement of sustaining and disruptive technologies. For purposes of clarity, we present a model which describes the interactions of these technologies more simply and concisely. This model, called the Cycle of Technology Disruption, consists of three phases.

1. Sustaining Technology

II. Rise of the Disruptive Technology

III. Disruptive Replaces Sustaining

![Figure 1 - Cycle of Technology Disruption](image)

Phase I: Sustaining Technology

During the first phase of the cycle, the sustaining technology in the market thrives along the mainstream market dimensions. The technology progresses with market demands and proceeds along a constant trajectory of growth. This system of growth continues until Phase III.

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\(^6\) Christensen, *Innovator’s Dilemma* p. xv

\(^7\) Christensen, *Innovator’s Dilemma* p. xxv.
Phase II: Rise of the Disruptive Technology

At some point in the sustaining technology’s reign as the mainstream favorite, a potentially disruptive technology begins to develop. It compares unfavorably with the sustaining technology along the mainstream dimensions, and consequently, does not penetrate the sustaining technology’s market. Since the disruptive technology generally costs less and offers some drastically different features than the sustaining technology, it finds an emerging market to enter. During phase II of the cycle, the disruptive technology establishes its customer base in this separate market. It must attain huge success and acceptance in this initial market to become disruptive in the sustaining technology’s market.

Phase III: Disruption

As a disruptive technology gains acceptance in its market segment, the promise of higher profitability gives the disruptive technology manufacturers the desire to enter the sustaining technology’s market. The disruptive technology rises significantly in performance, eventually meeting the performance demands of the sustaining technology. By this time, the sustaining technology’s performance has already exceeded the level demanded by its customers, and the customers become less willing to pay for improvements in performance. While the disruptive technology initially provides lower performance, it offers lower prices and higher performance along other dimensions appealing to a large number of the customers in this market. This acceptance of the disruptive technology drastically changes the market, redefines the market performance dimensions, and usually replaces the sustaining technology as the mainstream technology in that market.

2.3 Further Areas of Clarification

The process of disruption described above, based on Christensen’s model, is applicable in the study of several technologies. However, as a result of studying the history of MACSYM, we find that three aspects of Christensen’s model need to be extended.

Northeastern Pull

According to Christensen, all technologies feel a natural “northeastern pull”\(^8\) that leads them toward higher performance markets and thus higher gross margins. He claims that

\(^8\) Christensen, *Innovator’s Dilemma* p. 78.
“[m]oving upmarket toward higher-performance products that promised higher gross margins was usually a more straightforward path to profit improvement.”

Christensen thus confuses performance and gross margin as one dimension; in reality, they are independent from each other. As stated earlier in the paper, different market segments have different performance dimensions. Two technologies in separate markets cannot be compared in performance because their performance dimensions are not the same. As companies work toward higher markets, they do not always simply increase their product performance. In fact, companies occasionally have to lower their products’ performance along their original dimensions and increase their products’ performance along a different set of dimensions to move into these higher markets. This differentiation between higher performance and higher gross margin is exhibited by the evolution of MACSYM. As later sections of this paper show, MACSYM’s evolution demonstrates a “Northeastern Pull” toward markets of higher gross margins; but in ADI’s attempt to penetrate those markets, it actually lowered MACSYM’s performance along a few dimensions.

Response of Sustaining Technology

Christensen provides a set of strategies with which managers can respond to a disruptive technology. This set primarily focuses on entry into different markets; however, managers can do more. Aside from changes to marketing strategies, managers of sustaining technology can make an array of changes to their technology to respond to a disruptive technology. These changes to the technology are detailed in Section 6, which describes MACSYM’s own response as it enters Phase III of the Cycle of Technology Disruption. Any particular change is never guaranteed to succeed, but depends on the circumstance. In the case of MACSYM, these particular responses were not enough to reverse its path towards demise.

Multiple Disruptions

Christensen’s model provides a strong analysis of a disruptive technology redefining a single market. In this situation, a disruptive technology may target only the most relevant and appealing sustaining technology. Yet, as the technology’s performance increases in multiple dimensions, a successful disruptive technology can eventually cross into other markets and replace the sustaining technology in those markets. Thus, a disruptive technology does not always stop at one primary disruption. The forceful influence of a powerful disruptive technology can be felt in numerous and varied markets!

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9 Christensen, *Innovator’s Dilemma* p. 80.
10 Christensen, *Innovator’s Dilemma* p. 97.
3. Background History – the Beginnings

The story of MACSYM began long before the launch of the commercial product line. The inception of the idea, maturation of the division, and development of the design took roughly six to seven years. This section portrays the history of these preparatory years.

3.1. Analog Devices, Inc.

Analog Devices, Inc. (ADI) was co-founded in 1965 by two MIT alumnae, Matthew Lorber, and Raymond (Ray) Stata in Cambridge, MA. The firm began as a supplier of operational amplifiers.

Thereafter, the firm began providing a broader range of products to its existing customers, and so “entered the market for data acquisition components with instrumentation amplifiers, isolation amplifiers, logarithmic amplifiers, analog multipliers, and other analog signal conditioning products.” These were followed by analog-to-digital and digital-to-analog converters for interfacing analog signals to digital systems.

3.2. Diversification and Vertical Integration

In the early to mid 1970s, ADI was enjoying rapid growth. New marketing strategies were forming within Analog Devices to sustain and accelerate the growth, most important of which were diversification and vertical integration. Diversification involved diversifying the product line, thereby reaching out to a broader customer base. Vertical integration could be conceptualized as a set of building blocks. The idea was to take the small components that ADI manufactured, and put them together into larger functional units offering more value added for the same components. The motivation behind this strategy stemmed from the realization that many of Analog Devices’ potential customers might not have the technical expertise, time, or effort to construct large-scale units.

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11 http://www.analog.com/newsroom/timeline.html
12 1982 Annual Report, p4
from such low-level components. \(^{13}\) Therefore, ADI’s solution was to offer more highly integrated products, and to convince its customers that it was much more economical to buy integrated solutions from ADI than to make their own. In time, Analog Devices’ vertically integrated products would span various levels of complexity: from signal conditioning modules (at the lowest level)\(^ {14}\), to signal conditioning I/O subsystems such as their μMAC product line, to standalone measurement and control systems like the MACSYM, (at the highest level).\(^ {15}\)

According to MACSYM hardware design engineer Tom Kelly, at that time vertical integration was part of the business model for success. He illustrated the concept with an analogy to the Motorola of today: “Well, they’re vertically integrated. You can buy a cell phone chip and you can buy a cell phone. You can buy a pager chip and you can buy a pager. And that was the whole idea, to be successful you have to vertically integrate.”\(^ {16}\) Indeed, ADI saw vertical integration as a high priority at the time, and it influenced much of the companies product development in the 1970s.

### 3.3. Origins of the MACSYM

In 1972, during a trip to England, Ray Stata met a Norwegian named Ivar Wold.\(^ {17}\) He was impressed by Wold’s vision and abilities, so he recruited Wold to ADI and delegated him the task of discovering new product opportunities.\(^ {18}\) According to Wold, the computer companies were “flying high” at that time. In the spotlight were names such as Digital Equipment, Data General, Wang, and Prime, among other computer manufacturers. Stata wanted to get involved in this exciting field and asked Wold to explore it. Hence, an idea came about to combine the computer technology with ADI’s existing expertise in signal conditioning and data acquisition to make a specialized computer. The concept

\(^{13}\) Summary of Annual Meeting Address by Ray Stata, President of Analog Devices, March 14, 1978
\(^{14}\) 1978 Annual Report, p10
\(^{15}\) 1982 Annual Report, p8-9
\(^{16}\) Tom Kelly interview
\(^{17}\) Barbara Kagan interview
\(^{18}\) Barbara Kagan interview
appeared to have strong appeal because it also aligned with the strategy of vertical integration. These were the origins of the MACSYM.

In 1973, ADI formed a special Research and Development (R&D) called the Systems Development Group (SDG), and Ivar Wold was entrusted with its leadership.

Initially, the products of the SDG were not for general consumption, but rather excursions into factory automation for specific needs within ADI. Factory Automated Test System (FATS) was the primary example of this period. Though FATS was not viewed as a product that would come to market, it first introduced the idea “that computers could actually measure and control things”, and that was considered shocking back in 1970s. This concept eventually realized within the MACSYM.

3.4. Ivar Wold: Heterogeneous Engineer

Ivar Wold was the man who originally came up with the idea of MACSYM. Even though he received Ray Stata’s firm support, the adoption of a systems product such as the MACSYM did not come about without resistance within ADI, the components manufacturer. According to Ivar Wold, “there was some hard time in the company convincing the component people that it was even worth extending into something else.” Indeed, some persuasion is always required before an idea is adopted, especially if that idea appears unfamiliar, perhaps even risky. For a company specialized in components, such an ambitious systems effort as the MACSYM may have appeared ludicrous to some.

Confronted with resistance, the task of convincing ADI to adopt the MACSYM project was not easy. For the MACSYM to realize, not only did the physical machine and its software need to be engineered, but people within ADI needed to be engineered as well. They needed convincing, to suspend their doubts, offer their resources for, and show motivation for the new idea. This process is referred to as "heterogeneous

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19 Jay Kelly interview
20 Jay Kelly interview
21 Ivar Wold email to Victor Chang
22 Ivar Wold email to Victor Chang
engineering” in Donald Mackenzie book titled *Inventing Accuracy*. Our interviews consistently indicate that Wold possessed the attributes of a "heterogeneous engineer."

First, Ivar Wold possessed the social skills required of a heterogeneous engineer. He was described on most accounts as being “very persuasive” and a visionary. Others expressed a wariness about Wold’s persuasive abilities, expressing that he could easily “charm” one. One member of the SDG gave Wold’s leadership style an “A++”, being open, honest, and empowering, in contrast to a C-type leadership described as dictatorial and controlling.²⁴

Not only did Wold have the social skills required of a heterogeneous engineer, but he had the technical expertise that also commanded respect. His colleagues generally acknowledged that he was “brilliant.” He was trained, in his own words, as a “proverbial rocket scientist,” having obtained a B.Sc. in Aeronautics and Astronautics from Southampton University in England (1961-1965) with first class honors. He further honed his technical skill by doing postgraduate research at the Institute of Sound and Vibration Research at Southampton University. Because his research work required much instrumentation to be built, Wold gained knowledge in the field of electronics.²⁵ Wold’s numerous patents were evidence of his technical intuition. A combination of Mr. Wold’s persuasiveness, vision, and technical brilliance gained him the strong support from Ray Stata²⁶ and others executives, such as Cy Brown in Marketing²⁷. In 1975, the MACSYM was adopted by Analog Devices as an internal venture operation.²⁸ The Systems Development Group was also renamed the Measurement and Control Products group, or MCP.²⁹

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²³ Ivar Wold interview
²⁴ Jay Kelly interview
²⁵ Ivar Wold interview
²⁶ Ivar Wold interview
²⁷ Ivar Wold email to Victor Chang
²⁸ Analog Devices 1981 Annual Meeting Address, p10
²⁹ Ivar Wold interview
3.5. MACSYM-culture

Just as Mackenzie, in *Inventing Accuracy*, referred to a “gyroculture” that evolved around the gyroscope contraption\(^{30}\), here a sort of “MACSYM-culture” developed around the MACSYM measurement and control system. In other words, a whole set of knowledge, skills, ideas, and devices formed around the MACSYM. This MACSYM culture also entailed the following

- accumulation of skills, tacit knowledge, a repertoire of solutions
- experienced engineers
- innovative ideas
- cutting edge devices
- advanced facilities

Very few of the people in the MCP came from within Analog Devices.\(^{31}\) With the MACSYM, Analog Devices, an IC company, was delving into an entirely new domain. Although people were hired from within Analog Devices for the signal conditioning aspect of the machine,\(^{32}\) many others were recruited from outside of Analog Devices to satisfy the new computer expertise required for the MACSYM.\(^{33}\)

Many new ideas emerged as many problems were tackled for the first time. According to Ivar Wold, what was “particularly exciting was actually diving in and building a computer from scratch.” He explained that for the MACSYM, the group had initially planned to use a CPU provided by Data General. Unfortunately, Data General reneged their commitment late in the implementation, and the MCP was faced with a quandary of what to do: “We’re sitting here with a solution and no CPU. And we looked and said ‘Gee, it doesn’t look that hard, let’s just do it.’ [We] took a couple of months and built all the machine from scratch. And it worked.”\(^{34}\) That was a testament to the type of brainpower and energy existing within the core group working on MACSYM. This also reveals

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\(^{30}\) Mackenzie, p31

\(^{31}\) Ivar Wold interview

\(^{32}\) Ivar Wold interview

\(^{33}\) Ivar Wold interview

\(^{34}\) Ivar Wold interview
the engineering interest and technical emphasis of the group. At its inception, it was almost a purely engineering undertaking.\textsuperscript{35}

By the time the MACSYM idea came about, the core group consisted of less than a dozen members. These included Ivar Wold, Charles Ehlin, Jay Kelly, Mort Elbert, Charles Ranalli, Mike Lindheimer, and Bill Gonsalves.\textsuperscript{36} It was a close-knit team of engineers, technicians, and programmers, among others. A special camaraderie and environment developed within the early MACSYM group, which Jay Kelly, a MACSYM engineer, attributed to the leadership style and group dynamic at the time. For the core group, there was no concept of an 8-hour day. “We lived there,” spoke Jay Kelly, who reminisced of times when he would wake up at two in the morning and go to the office just to see who was there. According to Kelly, though the group knew they were by no means the profit center of the company, they were still driven by the feeling that what they were doing was important. They were also aware that their Research and Development group was placed in buildings and facilities completely separate from the rest of Analog Devices, perhaps because the focus of the MCP differed so greatly from the rest of the company. Barbara Kagan, Ivar Wold’s administrative assistant, also spoke of Ray Stata’s generosity, “Our group was funded completely by Analog Devices and Ray Stata gave full rein to Ivar and money and funding was unlimited.”\textsuperscript{37}

The core expanded quickly, based initially in University Ave. in Westwood, MA. Ben Rogers, who was hired into the group as a test technician, estimates that there were roughly 30 members at the time he joined in 1979.\textsuperscript{38} The group later grew to a few hundred\textsuperscript{39}, and occupied a large new building in Norwood, MA, where Analog Devices’ headquarters are situated today.\textsuperscript{40}

MACSYM marketing and engineering groups emerged to accommodate the rapid expansion of this business. The open, hard-
working culture of the MCP group led to the complete creation of a system within five years. The future of MACSYM, Analog Devices’ most ambitious systems project, seemed bright. The question remained, however, about where the MACSYM ought to be marketed.

3.6. Market and Company Environment Leading to Development of MACSYM

During the 1970’s, many developments related to measurement and control systems were taking place both in the marketplace and within Analog Devices. In the marketplace, there were new products that could measure and automatically control signal inputs and outputs. The range of existing products could satisfy both industrial and research purposes, and they became popular because users could now perform tests and processes more efficiently with these products. Analog Devices saw the potential in this market and decided to build their own system, called the MACSYM, to measure and control signals using microprocessor technology. At the time, Analog Devices was already manufacturing data acquisition components, such as signal conditioning devices and A/D converters that were used to measure signals. Analog Devices felt that these components could be used in their measurement and control system, and thereby accomplish the highest level of vertical integration. This section describes in detail the signal measurement and control marketplace, the new products being developed at the time, and Analog Devices’ motivation for developing the MACSYM.

Distributed Control Systems (DCS)

With the idea of computers in mind, Honeywell designed and introduced a specialized system that could provide automated process control for industrial purposes. In 1975, Honeywell introduced the TDC 2000, the world’s first distributed process control system (DCS)\(^41\). The TDC 2000 was based on a minicomputer and provided process controls for industrial applications. The TDC 2000 was revolutionary in that it eliminated single-loop controllers, divided up the control tasks among...
multiple distributed systems, and introduced the concept of a data highway to a plant\(^{42}\). Also, the TDC 2000 used CRT monitors to distill control information to operators. Through the CRTs, operators could easily see how all the inputs and outputs of a system and apply the control logic and algorithms necessary to the system’s tasks. The TDC 2000 became very popular, and it did not take long for every major process control company to produce its own version of the TDC 2000. Foxboro, Fisher Controls, Beckman, EMC Controls, ACCO Bristol, Taylor Instruments, Rosemount, Fischer & Porter, and Leeds & Northrup all came out with new DCS systems with most emulating Honeywell’s three-CRT operator station. These systems were high-priced, costing $50,000-$100,000. Besides having distributed control capabilities, they were extremely rugged, which made them ideal for use in industrial situations such as manufacturing plants.

**Programmable Logic Controllers (PLC)**

For users that either could not afford a Honeywell type system or did not need the full functionality of such a large-scale system, Programmable Logic Controllers (PLC) was a viable alternative\(^ {43}\). PLCs were created to replace the sequential relay circuits for machine control. The PLC controlled processes by receiving inputs and switching its outputs on or off based on simple logical combinations of the inputs. PLCs were one of the first special-purpose, computer-based devices that could be used by someone who was not a computer specialist. Programming could be done by anyone who was familiar with relay logic diagrams. PLCs were first introduced in the late 1960s by Modicon with the MODICON 084. The PLC industry soon became established after Allen-Bradley introduced their PLC\(^ {44}\). PLCs were relatively inexpensive, but were limited in what they could do. They did not possess the speed of DCS systems, and its limited memory capacity placed a ceiling on the

\(^{41}\) Control Magazine 6/99  
\(^{42}\) Control Magazine 12/99  
\(^{43}\) http://www.plcs.net  
\(^{44}\) Control Magazine 12/99
number of inputs and outputs that could be controlled. However, they were very attractive for their value and simplicity.

**Mid-Level Systems**

In the middle of the high-end distributed process control systems (DCS) and the programmable logic controllers (PLC), there existed a relatively open marketplace for moderately priced signal measurement and control systems. At that time, the market segment was occupied by minicomputer solutions. During the early 1970s, minicomputers were very popular for general purposes. The DEC PDP-8 came out in 1965, and by the early 1970s, the DEC PDP-11 was commonly used. To perform data acquisition and signal processing tasks, minicomputers were used with third-party vendor extensions. In the research and laboratory environments, minicomputers were used in conjunction with plug-in cards for processing the measurement and control signals of experiments. Customers for these mid-level minicomputer systems were mostly research institutions that sought the computing power of the minicomputer but did not require distributed control and industrial ruggedness.

With the advancement of microprocessor technology, an opportunity opened for a mid-level system that utilized microprocessors. Such a system would occupy less space than the minicomputers but offer similar signal processing capabilities. Analog Devices identified this opportunity to attack this mid-level measurement and controls market. Because they were early to identify the market opportunity in the mid 1970's, Analog Devices believed that the timing was right to compete against minicomputers for the space in the market. The MCP group within ADI began its first effort to penetrate the space with the MACSYM I in 1976. It soon became a sustaining technology in that market.

**4. Phase I – Sustaining Technology**

As was mentioned earlier, sustaining technologies improve along the mainstream dimensions of a market. Analog Devices produced the initial MACSYM as a product that entered the mid-level market in
measurement and control systems. Through the MACSYM, Analog Devices wished to “offer a complete computer-based measurement and control system incorporating isolation, signal conditioning, analog and digital computation, data conversion, programmable logic, memory and… provide varying amounts of computing power and flexibility to meet the needs of more applications, while keeping costs under those of equivalent minicomputer-based systems”\(^{46}\). The dimensions along which MACSYM intends to improve were similar to the mainstream dimensions in the market defined by the dominant minicomputer solutions. As the MACSYM progresses along these dimensions, it becomes a sustaining technology and enters Phase I of the Cycle of Technology Disruption.

4.1 MACSYM I

The original stated purpose of the MACSYM was to be a fully integrated Measurement And Control SYsteM. The MACSYM was developed specifically to acquire, reduce, store, present, and output real-time information in laboratory, research, and process control applications. During the period before the MACSYM I, many laboratory and research technicians built their own systems to perform such tasks. However, this was no easy task: significant amounts of experience in computer components were required to assemble these systems correctly. Since no single manufacturer supplied parts for an entire system, many components had to be obtained from different manufacturers. Thus, piecing together these acquisition systems took large amounts of configuration and set-up time. Analog Devices’ intention with the MACSYM was to minimize the time and experience required to configure, setup, program, and operate in the end-user’s environment\(^{47}\).

The alternative to assembling a measurement and control system was to use the existing solutions made for the minicomputers at the time. Minicomputers with such solutions, such as the DEC PDP-11 with data acquisition plug-in cards, could perform the measurement and control tasks for the mentioned mid-level market. According to Professor Forbes

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\(^{45}\) Ceruzzi, Paul. *A History of Modern Computing* p.243-245  
\(^{46}\) Analog Devices 1980 Annual Report p.9  
\(^{47}\) Analog Dialogue, Volume 13, Number 1 p.3
Dewey of MIT, there was one product based on the PDP-11 series, called MINC, that was a dominant player in this arena. However, noted Dewey, “It just cost an arm and a leg… a huge fortune for those things.”

Professor George W. Pratt, also of MIT, once used a PDP11/03 for data acquisition purposes. His machine was purchased for roughly $22,000 and was the size of a stove. Not surprisingly, the high prohibitive price for minicomputers was often times too expensive for laboratories.

The less-expensive MACSYM I fully integrated both hardware and software, making it exceptionally easy to connect analog and digital signals into the computer. More specifically, signal conditioning cards were the cards plugged into the back of the MACSYM I that gathered inputs and/or produced output signals. The user simply had to select the card appropriate to the application. Besides the ability to easily plug in many different conditioning cards, the MACSYM I ran easy-to-use software so that researchers who were not computer experts could easily design, prepare and run programs.

When Analog Devices released its first version of the MACSYM, the MACSYM I, the units were distributed to laboratories and research facilities to gauge customers’ responses to the integrated system. The positive feedback from the customers about the MACSYM I marked the official start of the development of the MACSYM II in August 1977. Prior to the release of the next generation of the product line, ADI put the MACSYM I on the market in February 1978.

4.1. MACSYM II and MACSYM 20

In 1978, Analog Devices released the MACSYM II. The MACSYM II evolved into a complete and “low cost” system that was compacted into a single desktop unit. Built with a 16-bit processor, console terminal, tape storage, interactive display, and a growing number of signal conditioning analog/digital input/output (ADIO) cards, the hardware of the MACSYM II was better than many standalone machines.

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48 Prof. Forbes Dewey interview
49 Prof. George W. Pratt email to group
50 News Circuit, Volume 1, Number 1 p.1
51 Analog Devices, 1978 Annual Report p.8
made for data acquisition and testing\textsuperscript{52}. ADIO cards could be added to the MACSYM as easily as expansion cards can be added to PCs today. As soon as the ADIO signal conditioning cards were plugged into the machine, the user could immediately read inputs or write outputs in his own application programs.

According to Ivar Wold, much of the architecture of the MACSYM II was based on Data General’s SuperNOVA machine\textsuperscript{53}. When Data General created the first model of the SuperNOVA in the early 1970s, it quickly became an early competitor to DEC. Although the SuperNOVA minicomputer had limited primitive protection features, the machine was a faster, cheaper alternative to the more expensive DEC PDP-11. In 1978, systems that were comparable to the MACSYM were the DEC’s PDP-11/34C and Fairchild’s 9400 series.

The specifications of the MACSYM II system showed how the MACSYM product line first improved along its mainstream dimensions. Although the MACSYM I had a digital processor, the MACSYM II utilized a 16-bit digital CPU built on Schottky TTL that integrated bit-slice technology for optimum speed and low power consumption\textsuperscript{54}. At the time, this CPU was less powerful than the most current DEC PDP-11, but the MACSYM II’s $9,990 price tag made the machine very attractive. Equipped with up to 64 kilobytes of memory, the MACSYM II was now able to log data and run more applications than its precursor, the MACSYM I. In addition, there were over a dozen ADIO signal conditioning cards available for the MACSYM II, while the MACSYM I did not have the same variety of input/output capabilities.

A new part of the MACSYM product line, called the MACSYM 20, was released with the MACSYM II. The MACSYM 20 acted as a front-end to the MACSYM II. The front-end was a small system that could house and collect information from ADIO cards. According to applications engineer Bill Schweber, “[The MACSYM 20] was really to allow more physical I/O and to physically distribute the I/O so that people wouldn't have to run long signal cables back to the central point.” He

\textsuperscript{52} Analog Dialogue, Volume 13, Number 1 p.3
\textsuperscript{53} Ivar Wold Interview.

\begin{quote}
“A bit-sliced part] is bipolar technology, this is before MOS. Take a machine, typically [it would] be a 64-bit architecture in those days like a big IBM mainframe, and slice the thing one bit wide. So you have these building blocks that are one-bit wide whole computer[s]. [You] would stick these together beside each other. If you want an 8-bit machine use eight of them.” –Jack Memishian, ADI hardware engineer
\end{quote}
explained that this greatly improved signal integrity, shortened cable runs, and offloaded the main CPU in the desktop unit, which was already “working hard enough to manage the keyboard, the screen and the disk drive.” It was possible to connect the MACSYM 20 to the MACSYM II by a IEEE-488 cable so that the MACSYM II could process inputs from its own ADIO cards as well those contained in multiple MACSYM 20s. This design improved the modularity of the system and allowed for up to 160 simultaneous inputs from separate ADIO cards.

Besides the upgrades in hardware and processing capabilities, the MACSYM II improved on its software capabilities. According to several of our interviews, one of the “best” parts of the MACSYM II and its latter generations was the MACBASIC environment. MACBASIC, a descendent of the BASIC programming language, was both easy to learn and easy to use. Because of this, there was no need for prior software experience or a separate development system. Interfacing with ADIO cards was relatively simple and somewhat generalized in the MACBASIC environment. One unique quality of MACBASIC was its ability to multitask. At the time, other computers ran with a BASIC environment, but none had the same multitasking capabilities. This capability allowed users to handle inputs and outputs simultaneously (as opposed to sequentially). This built-in multitasking simplified much of the programming logic required by the engineers and technicians who used the MACSYM II. Also, multitasking allowed the MACSYM II to perform a number of functions that would otherwise require several independent systems.

With the new improvements along its mainstream dimensions, the MACSYM was capable of being used for new applications. In laboratory automation, the MACSYM II was able to be used in everything from Pharmaceutical, Neurological, and Ophthalmological Research, to Energy Management Research (Measuring battery lifetimes) and Petrochemical Pilot Plants (Simulation of oil refinery controls).

40 K=0.5
50 L=5
60 X=AIN(8,0)
70 AOT(0,1)=K*SIN(X)
80 IF X>L DOT(1,1)=1
90 IF X< L DOT(1,1)=0
100 WAIT .5 GO TO 60

“This program assigns values to variables K and L. Instructs MACSYM 2 to input analog data (AIN) from card slot 8 channel 0, set the analog output (AOT) of card slot 0 channel 1 to K times SIN(X). Compare X to L. If greater, sound alarm on channel 1; if less, turn off alarm. Wait 1/2 second, read again. It’s that basic.” – MACSYM 2 advertisement on MACBASIC

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54 Analog Dialogue, Volume 13, Number 1 p.3-4
55 Bill Schweber interview
56 Catherine Stevens, Ben Rogers, Bill Schweber, and Ivar Wold interviews
57 Analog Dialogue, Volume 13, Number 1 p.12-14
After Analog Devices introduced the MACSYM II, the system began selling immediately. The first introduction of the MACSYM II to the public came on October 15th, 1978 at the Instrument Society of America Show\textsuperscript{58}. Analog Device’s booth was very heavily attended at the ISA show, and the follow-up inquiries from interested customers produced the initial base of first orders for the MACSYM II. In the 1979 Annual Report, Analog Devices accredits its $7.3 million increase sales to the MACSYM II and the acquisition of Computer Labs. In the 1980 Annual Report, the sales of the MACSYM II beat expectations for the year and bookings exceeding expectations. Analog Devices sold over 1000 MACSYM machines by 1980. Analog Devices even began publishing MCDigest and the Macsymizer, periodicals informing customers of new MACSYM developments and sample applications. In the 1982 Annual Meeting Address, it was announced that MACSYM sales had exceeded the original five-year-plan goal for the product line. At the time, the company included the MACSYM product line as a significant contributor to its future revenues.

Table 3 - Some Typical MACSYM II Signal Conditioning Cards and Applications\textsuperscript{59}

<table>
<thead>
<tr>
<th>Signal Functions</th>
<th>Card Identification</th>
<th>Features</th>
<th>Typical Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital I/O</td>
<td>DIN01, DIN02</td>
<td>16-Channel opto-isolated AC or DC Input</td>
<td>5 to 24 volt AC/DC input range</td>
</tr>
<tr>
<td></td>
<td>DOT01</td>
<td>16-Channel opto-isolated Open-collector output</td>
<td>TTL compatible High current output</td>
</tr>
<tr>
<td></td>
<td>AOC04</td>
<td>4-Channel unipolar D/A converter</td>
<td>Output voltage 0 to 9.990V dc 10-bit resolution</td>
</tr>
<tr>
<td>Thermocouple Cards</td>
<td>TIC03</td>
<td>4-Channel Isolated</td>
<td>Factory preset gain 128, 256, 512, 1024</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>INT01</td>
<td>8-Channel Isolated Process Interrupt</td>
<td>Isolation Selectable switch contact debounce</td>
</tr>
</tbody>
</table>

\textsuperscript{58} Analog Devices 1978 Annual Report p.8
\textsuperscript{59} Analog Dialogue, Volume 13, No. 1, p.9
4.2. MACSYM 150/200/350

In 1982, Analog Devices released its next generation of the MACSYM product line. This included the MACSYM 150 and the MACSYM 200\(^6\). Both were improved versions of the MACSYM II and the MACSYM 20, respectively. The combination of the MACSYM 150 and the MACSYM 200 was called the MACSYM 350.

From the hardware perspective, the MACSYM 150 had a 5 MHz 8086 microprocessor CPU chip and a 8087 math coprocessor chip. The precursor to the MACSYM 150, the then-famous MACSYM II, had a 16-bit assembled CPU. The MACSYM 150 took advantage of the advancements in fabrication technology with its *integrated* microprocessor chip. The MACSYM 200 took advantage of the same advancements: the MACSYM 200 now had an 8080 microprocessor instead of a Z80. The system was capable of handling up to 1-megabyte of main memory—over 10 times its previous capacity. Also, the introduction of the floppy disk drive and the 10-megabyte Winchester hard drive gave users the ability to store large amounts of information reliably in a relatively inexpensive form of media.

Due to advancements in multiplex design, the MACSYM 150

\(^6\) MACSYM 150/350 System Digest p.1-5
could now read from up to 256 ADIO signal conditioning cards with multiple MACSYM 200s. In addition, the number of different ADIO signal conditioning cards increased with the introduction of the MACSYM 150. There were now over two dozen cards that were capable of taking various input and output signals. With the wider variety of cards, the MACSYM product line could be used in more applications. An improved color display, detached keyboard, and floppy disk drive also made the system more flexible and easier to use. These improvements in MACSYM 150 hardware were complemented by the improvements in its software.

The BASIC environment graduated to version 3 of MACBASIC, which took advantage of the MACSYM 150’s new hardware. The software selection of the system continued to grow as well. Because of the increase in RAM and disk space of the system, the MACSYM 150 was capable of running much larger applications. From its growing number of applications, it is apparent that the MACSYM was beginning to grow abilities beyond data acquisition and signal processing. At this point in time, it appeared that the MACSYM line was continuing to improve along its mainstream dimensions as a complete system for measurement and control in the laboratory and research field.

Table 4 - Interesting Examples Showing the Diversity of MACSYM applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical research</td>
<td>“At the City of Hope, a world-famous medical research center, doctors are using a MACSYM 2 for biological experiments in the neurosciences...sensing and controlling neural discharge.”</td>
</tr>
<tr>
<td>Process Control --Fiber Optics</td>
<td>MACSYM 2’s and later MACSYM 350’s were used to measure temperature and strain on fiber optic strands, so that very thin strands could be made without the glass breaking when pulled.</td>
</tr>
<tr>
<td>Navigation</td>
<td>The famous sea explorer, Jacques Cousteau, employed a MACSYM 150 unit on board his Alcyon ship for navigational purposes.</td>
</tr>
<tr>
<td>Product Test</td>
<td>“Englehard Corporation, a multibillion-dollar-a-year producer of chemicals, precious metals and minerals, uses a MACSYM 2 to automate the life testing of electrical contacts.”</td>
</tr>
<tr>
<td>Process Control—Juice Manufacture</td>
<td>“Adams Packing, a leading manufacturer of citrus juices, uses MACSYM 2 for closed-loop control for steam on their concentrate juice evaporator.”</td>
</tr>
</tbody>
</table>

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61 Ben Rogers interview  
62 MACSYM 2: Automated Testing Made Easier brochure  
63 Ben Rogers interview  
64 Ben Rogers interview  
65 MACSYM 2: Automated Testing Made Easier brochure
5. Phase II – The Rise of Disruptive Technology

In this section of the paper, the second phase of the cycle of technology disruption and how it applies to the MACSYM project is discussed. During the second phase of the cycle, a disruptive technology is on the rise. The disruptive technology has a strong foothold in its own markets and is starting to make its way into the markets of the sustaining technology. As the disruptive technology takes on more and more characteristics of the sustaining technology and continues to improve along the mainstream dimensions, the disruptive technology is able to compete directly with the sustaining technology and starts posing as a threat to the sustaining technology.

In the case of the MACSYM project, MACSYM was a sustaining technology that was disrupted by the personal computer technology, in particular the IBM PC/XT. Initially, the MACSYM and the personal computer operated in completely different markets. The specialty of the MACSYM was providing signal measurement and control for customers in the mid-level research and laboratory market, while the personal computer was meant as a general-purpose machine that could be used to perform office-related tasks like word processing or spreadsheets. However, as the personal computer, in particular the IBM PC/XT, became more widespread and popular, many new applications for the personal computer were invented. One of these new applications for the PC was signal measurement and control. Because of this, the PC became a disruptive force to the MACSYM and began to challenge the MACSYM in the measurement and control market. However, the PC did not become a disruption to the MACSYM overnight. There was a lot of history and many factors involved in this process, and this section will look in detail at the history of the PC, how the PC fits into Christensen’s model of disruptive technology, and the rise of the PC as a disruptive technology to the MACSYM product.

60 MACSYM 2: Automated Testing Made Easier brochure
This section will be split into four parts. The first part will explain Christensen’s concept of a disruptive technology and describe the characteristics of a disruptive technology. The next part will discuss the development of the personal computer leading up to the introduction of the IBM PC/XT. Then, the third section will show how the IBM PC/XT fits into the model for disruptive technology. Finally, the fourth section will detail the success and standardization of the IBM PC platform.

5.1. Three Characteristics of Disruptive Technology

On the surface, a disruptive technology does exactly what its name suggests – it disrupts and threatens the future of less fortunate technologies. A disruptive technology disrupts the market of a sustaining technology by completely changing the way consumers think about a market. Usually, a disruptive technology arises in a market different than the mainstream market of the sustaining technology, but as the disruptive technology develops and improves, the disruptive technology can start satisfying the demands of the mainstream market. The disruptive technology can then become a viable competitor to the sustaining technology.

According to Christensen, disruptive technologies have three main characteristics.

- First, disruptive technologies are generally simpler, cheaper, smaller, and often more convenient to use than sustaining technologies. Because of their simplicity and lower cost, disruptive technologies will offer lower margins and thus lower profits.

- Second, disruptive technologies normally are first introduced and commercialized in insignificant or emerging markets. Disruptive technologies usually do not start off in the same market as the market of the sustaining technology; they only move to the mainstream market after the disruptive technology has improved enough to meet the demands of the mainstream market.

- Third, disruptive technologies in the near-term offer worse product performance along the mainstream market dimensions. Initially,
the most profitable customers of the sustaining technology generally do not want, and sometimes cannot even use products based on disruptive technologies.\textsuperscript{67} Disruptive technologies survive because they have other features the new customers in the insignificant or emerging markets value. Disruptive technologies work by building market share in these lower markets and improving its capabilities enough to enter the mainstream market.

Christensen’s concept of disruptive technology can be applied to the case of MACSYM. As mentioned in the Phase I of this paper, MACSYM was a sustaining technology in the mid-level research and laboratory signal measurement and control market. When the MACSYM first came out, it was incredible in that it could fit on a desktop and had enough processing power to handle a multitude of signal inputs and outputs. However, Analog Devices was not the only company in the 1970s trying to develop a desktop computer that could perform user tasks. While MACSYM was being developed, many companies entered into the personal computer market hoping to capture their share of the pie. The personal computer was not yet a threat to the measurement and control systems market, but it loomed as a potentially disruptive technology. The rise of the PC marks the beginning of Phase II of MACSYM’s evolution through the Cycle of Technology Disruption.

5.2. Personal Computers

During the 1970s, the idea of a personal computer was gaining popularity. By the start of the 1970s, the mainframe and minicomputer had already been introduced, and microprocessor technology was gaining momentum. The next logical step would be a much smaller and inexpensive computer that could take advantage of this microprocessor technology. The introduction of the Altair 8800 in 1975 launched the personal computer market, and subsequent models of the personal computer by Apple Computers and IBM defined the personal computer marketplace.

\textsuperscript{67} Clayton Christensen, \textit{The Innovator’s Dilemma}, pp. xv
The Altair 8800 was the first – the very first – full-fledged personal computer on the market. The Altair was introduced in January 1975 in *Popular Electronics* and was designed primarily by H. Edward Roberts of Micro Instrumentation and Telemetry Systems (MITS) in Albuquerque, New Mexico. The Altair was based on Intel’s 8080 microprocessor and was surprisingly inexpensive. It cost as little as $400 and contained sixteen expansion slots, allowing users to expand and customize their Altair. The physical appearance of the Altair consisted of a rectangular metal case, a front panel of switches that controlled the contents of internal registers, and small lights indicating the presence of a binary one or zero. The Altair could not do very much because of the limitations of its hardware and lack of software support, but the Altair started a burst of energy and creating in computing for the next three years.

The next major milestone in the personal computer market was the Apple II. The Apple II had excellent color graphics capabilities and was very user-friendly. It contained expansion slots, allowing Apple and other companies to expand Apple’s capabilities. Also, using BASIC for Apple allowed programmers to write imaginative software for the Apple platform. The Apple II was a success, but the personal computer to this point did not yet challenge the computer establishment of IBM, Digital, or Data General.

In 1981, the IBM’s version of the personal computer, the IBM PC/XT, revolutionized the personal computer marketplace. The IBM PC was based on the Intel 8088 processor, used 16-bit words, ran on the MS-DOS operating system, and had five empty expansion slots. Through IBM’s clout, the machine was an immediate success. The IBM PC standardized the personal computer and paved the way for many new software and hardware applications for the IBM PC. With the introduction of the IBM PC, there were no more doubts about the personal computers as serious rivals to mainframe and minicomputers.

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68 Stan Augarten, *BIT by BIT: An Illustrated History of Computers*, pp. 270
69 Paul E. Ceruzzi, *A History of Modern Computing*, pp. 227-228
70 Paul E. Ceruzzi, *A History of Modern Computing*, pp. 266-267
71 Stan Augarten, *BIT by BIT: An Illustrated History of Computers*, pp. 280
5.3. Personal Computers as a Disruptive Technology

Using Christensen’s model of disruptive technology, the personal computer can be viewed as a disruptive technology to the MACSYM. Compared to the sustaining technology of the MACSYM, the personal computer takes on the three characteristics of disruptive technology. This section will discuss in detail how the personal computer fits each of the three characteristics.

The first characteristic is that disruptive technologies are generally simpler, cheaper, smaller, and often more convenient to use than the sustaining technology. The MACSYM was a complex system made specifically to measure and control a variety of signal inputs and outputs. In addition to the knowledge required to connect all the signal inputs and outputs, a user of MACSYM also needed BASIC programming experience to control these signals. On the other hand, the personal computer was a general system that required basic computer knowledge to use. The personal computer did not have any specific, complex functionality and was very flexible in its uses.

Also, the MACSYM was much more costly than the personal computer. Because of MACSYM’s specialized functionality, Analog Devices was able to mark up the MACSYM and charge a premium to its customers. For example, the MACSYM II in 1978 was priced at $9,990.72 The personal computer was priced much lower than MACSYM. The Apple II sold in 1977 for $1,195 (with 16 K of RAM and without a monitor)73, and in 1981, the IBM PC/XT was priced at $1,565.74 The IBM PC/XT was a lower margin product, but IBM PC was a financial success because of its sales volume.

The second characteristic is that disruptive technologies normally are first introduced and commercialized in insignificant or emerging markets. The MACSYM was specifically aimed at the signal measurement and control market for research situations and laboratories. The personal computer was aimed for general use and thrived in markets that were just starting. For example, the Apple II thrived in the video

72 Analog Dialogue, Vol 13, No. 1
73 Stan Augarten, BIT by BIT: An Illustrated History of Computers, pp. 280
game market, and the VisiCalc software helped Apple penetrate the office environment. Word processing, accounting, and game software, applications just emerging at the time, were all available for the IBM PC, and the combination of the IBM PC and the Lotus 1-2-3 spreadsheet software was very successful in the office applications market.\textsuperscript{75} When it first came out, the personal computer did not intend to enter into the signal measurement market.

The third characteristic is that disruptive technologies in the near-term offer worse product performance along the mainstream market dimensions. The customers of the sustaining technology often do not want, and sometimes cannot, use the disruptive technology because the disruptive technology cannot meet the customer’s product demands. This characteristic holds true for the personal computer. When the IBM PC was first introduced, it did not have any signal measurement and control capabilities. Users of the MACSYM at this time had no use for the IBM PC, and the IBM PC did not pose as a threat to MACSYM’s markets when the PC first came out. In the general opinion of those interviewed, technically, the PC wasn’t superior at first, and did not seem like a threat to the MACSYM. However, as a result of IBM’s clout, the IBM PC rose in popularity, and new software and hardware applications were being devised for the increasingly widespread platform. The next section will discuss the standardization of the IBM PC and some of the new applications for the PC platform.

5.4. Standardization of the IBM PC

Through IBM’s clout in the computer industry and software applications like Lotus 1-2-3, the IBM PC became a big success in the marketplace. In 1981, the year it was introduced, the IBM PC sold about 35,000 units. By 1983, that number had grew to 800,000.\textsuperscript{76} Because of its popularity, the IBM PC became the standard machine and platform for the personal computer market. Also, companies like Compaq and Phoenix Technologies were able to reverse engineer the BIOS of the PC, making it

\textsuperscript{74} IBM History, http://www.ibm.com/ibm/history/
\textsuperscript{75} Paul E. Ceruzzi, \textit{A History of Modern Computing}, pp. 268
possible to build IBM PC clones. Clones made the IBM PC platform even more widespread and drove down the prices of personal computers.

The success of the IBM PC platform created a boom in the software and hardware development industries. Many third party vendors started developing software applications that could fully take advantage of the PC’s capabilities, and hardware solutions were developed to take advantage of the IBM PC’s five expansion slots. One of these hardware solutions was a plug-in card that could perform signal data acquisition through inputs and outputs. Also, software that could use the PC to perform signal processing and plot signals were slowly becoming available. With these hardware I/O cards and the appropriate software, the IBM PC could emulate a MACSYM machine. These hardware cards and software proved to be a big disruption and threat to the MACSYM line of products. The next phase of the paper will discuss in more detail how the IBM PC penetrated MACSYM’s measurement and control market.

**6. Phase III - Demise of Sustaining Technology**

Third party extensions to the IBM PC eventually provided the PC the ability to perform measurement and control functions. As soon as that happened, the PC suddenly became a real threat to MACSYM and brought it into the third phase in the Cycle of Technology Disruption. This phase is characterized by two distinct sequence of developments:

- The disruptive technology provides compelling solutions similar to those provided by the sustaining technology.
- The sustaining technology responds to the disruptive technology’s success in its own marketplace through a series of actions.

**6.1. Threat of the IBM PC Becomes Clear**

The widespread success of the IBM PC had begun to unify the standards of the personal computer. As a result of these standards, a number of development communities formed centering on the platform.

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76 Stan Augarten, *BIT by BIT: An Illustrated History of Computers*, pp. 280
The years following the emergence of the IBM PC were in part characterized by a number of hardware and software applications for the IBM PC. In fact, many companies that had previously developed hardware and software for minicomputers evolved their businesses to embrace the IBM standard.

Two key advancements in hardware and software directly affected MACSYM. The first advancement was signal acquisition cards for the IBM PC. These cards plugged into the bus of the IBM PC through the expansion bays in the back plane of the computer. In turn, analog and digital inputs could be plugged into these cards. Measurement and signal analysis could thereby occur on the IBM PC. This was a compelling solution that raised the utility of the IBM PC in the measurement and control market.

Nonetheless, the operating system for the IBM PC, DOS, was not yet equipped to perform the real-time signal analysis needed in control systems. DOS was not a multitasking operating system making real-time signal analysis difficult. Multitasking was so crucial to real-time signal processing that MACSYM never changed its operating system from CCP/M, a multi-tasking operating system, to MS-DOS.

However, Intellution, a company that had previously designed signal acquisition solutions for the PDP-11 focused its efforts on the IBM PC in the early 1980s and unveiled a multitasking emulator for the IBM PC in 1984. Steve Rubin, a manager at Intellution Corporation, introduced “The Fix, ” touted as the world’s first PC-based control system, at the 1984 Instruments Society of America conference. Interestingly, it was at this same exact conference 6 years earlier that Analog Devices unveiled its MACSYM II and signed on many of its initial customers. Intellution’s software director, Alan Chisholm, had created a multitasking shell that could run on the DOS operating system. According to Control Magazine, a control systems journal, Alan Chisholm “figured out a way to partition DOS so that it could work in a multitasking mode, and PC controls were born...The system [The Fix] lets a PC monitor real-time I/O, execute DOS functions such as file management, and perform PID control.
on 16 loops simultaneously.” Other companies including Heuristics and Centec released similar hardware and software solutions called Onspec and CAMM, respectively, for the IBM PC by early 1984.

The years following 1984 quickly gave rise to numerous advancements not only in hardware but also other software capabilities in databases and graphics. By 1984, several firms had realized the opportunity for measurement and control systems based on the IBM PC. According to Control Magazine, “several companies had jumped on the PC bandwagon, including USDATA, which released FactoryLink.” FactoryLink was the PC industry’s first real-time PC database. FactoryLink allowed more complex analysis of larger amounts of data than had previously been possible on the PC-based solutions.

The complimentary advancements continued with Computer Technologies Corporation introduction of ScreenWare, one of the first PC-based control automation graphic software packages shortly after “The Fix” was released. Tim Root, marketing communications manager for CTC described ScreenWare as “the standard in the automation industry for easy-to-use animated graphics software for real-time monitoring and controlling of process or machine applications.” The ScreenWare system raised the visual appeal of the measurement and control solutions for the PC platform. For example, signals were no longer plotted using simple ASCII characters but were plotted instead with colorful shapes and smooth curves.

While the PC-based solutions in 1984 were not as robust and complex as the solutions provided by MACSYM, they began chipping into the measurement and control systems market. These solutions, fully compatible with the popular IBM PC, were priced significantly cheaper than MACSYM. Through the years, the PC-based measurement and control systems had become more technically compelling and began gaining acceptance in the value driven measurement and control system market of low-level to mid-range applications. The threat of the IBM PC as a disruptive technology to MACSYM became apparent. MACSYM’s future success depended on its responses to this disruptive technology.

77 Control Magazine, 11/26/2000
6.2. Key Responses to a Successful Disruptive Technology

When leaders of a sustaining technology are confronted with a successful disruptive technology, they can choose from a set of responses to the competing technology. Christensen also discusses a model in *The Innovator’s Dilemma*, in which a sustaining technology responds to a disruptive technology. However, the model Christensen presents focuses solely on the methods and timing of the sustaining technology moving into a new market. The sustaining technology response model presents a different set of responses based on whether or not the technology is evolving on the market. These responses are detailed below:

- **No Response.** The company can attempt to actively or non-actively respond to the disruptive technology by trying not to change its normal activities of before. Thus, the sustaining technology would attempt to continue progress along the same sustaining dimensions as before.

- **Move of Technology to Different Markets.** This response is characterized by the company changing its current products and latter products to fit into new applications and/or new markets. In particular, the company would continue efforts to move the technology into the higher marketplaces characterized by more complex technology and higher profit margins. This response is similar to the natural trajectory path, referred to as the “Northeast pull,” described by Christensen in *The Innovator’s Dilemma*. However, in many cases this move of the technology to different markets is characterized by a change in the mainstream dimensions of the technology.

- **Tepid Acceptance of Disruptive Technology Platform.** The company could respond to the disruptive technology by partially accepting the disruptive technology platform. This approach would involve creating a new product that uses the disruptive technology’s paradigm or system. In addition, the company would continue its traditional sustaining technologies efforts.
• **Full Acceptance of Disruptive Technology Platform.** This response involves the company fully endorsing the disruptive technology. Companies, which choose this response, change their sustaining technologies to work with or on the disruptive technology’s model or paradigm.

By 1984, the MACSYM team had begun to respond to the disruptive technology. The leaders of the MACSYM project used a combination of the responses listed above to perpetuate the life of their sustaining technology.

### 6.3. Move of Technology to Different Markets.

The MACSYM team began to realize that the mid-range laboratory market was no longer receptive to their computers due in a large part to the IBM PC. Analog Devices also recognized that its component customers such as Honeywell and Foxboro had been successful at selling complex process automation computers. As a result, leaders of the MACSYM team shifted their business strategy away from the laboratory market to the higher more complex industrial market. A new set of mainstream dimensions consisting of features and ruggedness instead of simply performance characterized the latter MACSYM products.

The 1984 Analog Devices Annual Report describes this technological change and states: “Prospects for continued growth in measurement and control systems were enhanced by the October 1984 introduction of an array of new products. These new products are aimed at distributed automation needs in factories and process plants, and thus are capable of operating in harsh environments.

One of first new products targeted toward the industrial market was the MACSYM 260. During 1983, Analog Devices released the MACSYM 250, a measurement and control unit that could contain a number of ADIO cards and could be directly programmed with MACBASIC. The appearance of the MACSYM 250 resembled earlier products such as the MACSYM 200. According to Ben Rogers, who had worked on the program for burning the MACSYM 250 EPROMs, “They
were more like M.200’s but had some of the workstation smarts of the 150 built into them.”

However, by 1984, the MACSYM group had re-engineered the MACSYM 250 entitled the “Programmable measurement and control unit,” in a 1984 ADI MCDigest, and released the MACSYM 260 entitled in the same article as the “Industrial Programmable Measurement and Control Unit.”

The MACSYM 260 was a rack mountable system encased in a strong sturdy chassis suited for the industrial market. The system could withstand high temperatures and strong vibration. A 1984 MCDigest stated that “its [MACSYM 260] temperature and vibration specs make it an ideal high performance system for the factory floor.” Similar to previous MACSYM models, a number of digital and analog inputs could be plugged directly into the system. This allowed the system to perform process control as a standalone machine.

MACSYM had begun its movement into a higher market. The company followed on with a marketing plan aimed at the factory automation market. Ray Stata, President and CEO of Analog Devices at the time described the MACSYM 260 as “a ruggedized controller optimized for high performance data acquisition, analysis and control in plant floor environments.”

The MACSYM 260 could be used in conjunction with a workstation hundreds of feet away in a potentially less harsh environment.

Dennis Lonigro, Director of Engineering, recalls however that at one point IBM began to entertain the idea of developing an industrial computer. This prompted the MCP to make a deal with IBM. “Actually, we ended up working with them to some extent on defining that product. I even think we even had them produce some private label versions of that for Analog Devices.” Though it is not completely clear which were the privately labeled versions, Dennis Lonigro was probably referring to the MACSYM 120, to be discussed in the next section. IBM’s entrance into industrial markets signaled the beginning of the end for the MACSYM product line.
6.4. Tepid Acceptance of IBM Platform.

The MACSYM team continued its response to the IBM PC by not only evolving all its product lines into higher more complex systems but also by starting to accept the IBM PC platform. Analog Devices began to realize the other solutions from vendors such as Intellution.

**MACSYM 120**

In October of 1984, not only was the MACSYM 260 released but the MACSYM 120 was as well. These models show that MACSYM was experiencing the Northeastern pull into markets of higher gross margins. They were attempts to penetrate the industrial measurement and control market. The MACSYM 120 was essentially an IBM PC repackaged as a MACSYM and installed with the CCP/M operating system. The machine featured a DOS emulator providing the ability to run DOS-based applications on the MACSYM 120. According to hardware design engineer Tom Kelly, the MACSYM 120 was even painted gray to fit into the plant floor color scheme and environment.

Analog Devices described the system in its 1984 Annual Report: as “a plant floor workstation, and uses hardware built by IBM that is compatible with our entire measurement and control product line.”

Although the MACSYM 120 was one of the most powerful IBM PC machines, its performance was not as high in many ways as Analog Devices MACSYM 150 released in 1983. Some of the key differences between the MACSYM 120 and MACSYM 150 are listed in the table below:

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78 Analog Devices, 1984 Annual Report
79 Analog Devices, 1984 Annual Report
In fact, Analog Devices shifted its mainstream dimensions from computing performance to industrial grade computing capability. As shown in the table above that compared the MACSYM 120 and MACSYM 150 on specifications related to computing performance, the newer and supposedly more advanced MACSYM 120 seemed like a downgrade – it had a slower processor, less memory, and fewer expansion slots. The improvements in the MACSYM 120 were in robustness and IBM PC compatibility – features that were important for the industrial environments. The MACSYM 120 had different performance dimensions as the previous MACSYM models. With improvements in the new dimensions, it actually regressed along the original dimensions.

Although the MACSYM 120 seemed to be the most compelling compromise between the IBM PC technology and the MACSYM technology—a machine that could be the best of both platforms, its success in the marketplace pointed otherwise. Under the resellers agreement between IBM and Analog Devices, Analog Devices was required to purchase a set amount of IBM PCs a month regardless of how many computers they sold. This agreement eventually caused great financial pains to the MACSYM product as the MACSYM 120s were marked up higher than the IBM PCs. Inventories of MACSYM 120s soon began to swell, as customers were unwilling to pay more than the

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Table 5 - Comparison Between MACSYM 120 and MACSYM 150

<table>
<thead>
<tr>
<th>MACSYM 120</th>
<th>MACSYM 150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intel 8086</td>
<td>Intel 8086</td>
</tr>
<tr>
<td>Math Co-Processor:8087</td>
<td>Math Co-Processor: 8087</td>
</tr>
<tr>
<td>Speed 1.0</td>
<td>Speed: 1.5x faster</td>
</tr>
<tr>
<td>Memory:Max 640KB RAM</td>
<td>Max 1MB RAM</td>
</tr>
<tr>
<td>Monochrome Resolution</td>
<td>Hi Color Resolution, real time refresh of graphics</td>
</tr>
<tr>
<td>4 ports for MACSYM 120 Cards</td>
<td>6 Ports for MACSYM Cards</td>
</tr>
<tr>
<td>Compatible with IBM PC/XT</td>
<td>No Compatibility</td>
</tr>
<tr>
<td>Market to Industry</td>
<td>Marketed to Laboratories and Control Processes</td>
</tr>
</tbody>
</table>

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"IBM had the Value Added Reseller program, VARs,.. Basically, you signed up to buy X number, and if you didn’t sell X number, you just stockpiled them. And every month, X number would should up, if you sold them or not.” --Tom Kelly, MCP hardware engineer

80 Tom Kelly interview
IBM PC for a specialized desktop computer so similar to the IBM PC. Additionally, customer complaints of the slowness of the DOS emulator further divided the two technologies.

Tom Kelly further stated that many customers could not justify the several thousand dollar difference in price between the MACSYM 120 and the IBM PC since the two machines were so similar. In his opinion, there was little choice regarding the price. Analog Devices wanted to make a profit off these value-added machines and marking up the price of the IBM’s already high cost was the logical choice to them.

In addition to the high price of MACSYM 120, Analog Devices also found itself in another non-ideal situation. Analog Devices had entered the higher end industrial grade computing market; a market dominated for decades by companies such as Honeywell and Foxboro. These same companies were some of the largest customers of Analog Devices’ traditional component products. The situation of competing with long standing customers made management uneasy. On one hand, Honeywell and Foxboro may choose to discontinue the purchase of ADI components, impacting ADI’s traditional line of business. On the other hand, MACSYM continued success depended on its entrance into these new markets.

General Electric faced a similar situation in the 1950s with its general-purpose computer called OARAC for the U.S. Department of Defense. GE abandoned its development of the computer and instead decided to focus on technologies that were less risky. Several analysts speculated that a major reason behind this decision was that IBM was GE’s largest customer of vacuum tubes. In this scenario, GE’s existing value network discouraged its entrance into a new marketplace.

It appears that MACSYM’s competition with ADI’s customers, expensive price, and inexperience with the industrial market prevented this system from becoming widely successful. Clearly, a different response to the PC was needed.
6.5. Full Acceptance of IBM Platform

Analog Devices continued to see its diminishing sales of MACSYM products. By 1985, it had become clear to Analog Devices that their two responses of moving into higher markets and creating an IBM compatible machine were not as successful as hoped. The mid 1980s were characterized by a consolidation of groups and abandonment of products. Several other technologies within the MCP Division gained valuable resources and company attention. Analog Devices began to downsize the MACYSM project and move people to two other similar technologies—uMacs and RTI cards by 1985. The focus on these two technologies represented ADI’s decision to fully embrace the IBM PC platform.

MicroMacs (uMacs)

The MicroMac was a single-board version for data acquisition. The product line did not have its roots in the MCP division, but another division within Analog Devices. The MicroMac connected through an RS232 cable to the IBM PC, and thus could be located a hundred feet away by serial link. Software resident on the host computer could be downloaded to the MicroMac and executed locally, allowing for signal analysis and measurement and control of processes. MicroMacs were a somewhat robust solution for the IBM PC platform.

Real Time Information (RTI) Cards

Analog Devices further responded to the IBM PC by placing more resources to develop powerful RTI cards. RTI products began earlier in 1974, as a “Product Line Extension”. These cards were similar to the signal conditioning cards found in MACSYM devices. Originally made for other popular machines such as the DEC PDP-11, it was a few years into the MACSYM business when ADI began producing RTI cards for the PC. RTI cards plugged directly into the PC backplane and allowed for the connection of Analog and Digital inputs to the card to be processed on

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81 Analog Devices, 1981 Annual Report, p10
82 Bill Schweber interview
the local system. The cards were bundled with MACBASIC software allowing for measurement, control, and signal analysis. Bill Schweber noted however that "It was very reluctantly that Analog Devices got into the plug-in boards business for PCs". 83

Several engineers including Tom Kelly left the MACSYM project and focused on developing signal conditioning cards for the IBM PC. Many of the employees of the MACSYM division elected to leave the company as they found little work within ADI that matched their computer architecture or software expertise. In addition, a number of engineers left ADI to join various startup companies developing signal conditioning cards for the IBM PC.

6.6. Final Responses of the MCP

Major changes continued to occur in the MCP division. By 1989, MACSYM had been officially declared obsolete 84. The product had faded away, and Analog Devices allowed another firm to take over the maintenance and support for the product line. 85

While Analog Devices sold the uMacs to a firm called Azonix that still markets the product 86, the RTI Cards are still in production at Analog Devices at the time of this report (2000), though to a limited extent. The company shifted many of its resources away from these products by 1989 citing the low barrier to entry and low margins in the signal conditioning cards market. According to Dennis Lonigro, RTI grew for a long time, but “there were too many players that were fully focused on that kind of plug-in board product line.” Some serious competitors in this market were Data Translation and Metrabyte. 87

Analog Devices has since shifted its emphasis away from vertical integration strategies and instead it has focused on emerging technologies such as Digital Signal Processors (DSPs) and other Integrated Components (ICs). Interestingly, the digital signal processors that ADI has been focusing on in the last decade are somewhat similar to

83 Bill Schweber interview
84 http://www.analog.com/industry/ios/ios_faq.html
85 Dennis Lonigro interview
86 Dennis Lonigro interview, http://www.azonix.com/
MACSYM’s system of computer based signal processing. In part, DSPs
manage signal inputs and provide a host of efficient and complex digital
processing on these signals at the chip level instead of the system level.

7. Conclusion

In reflection of the MACSYM project, Ray Stata, Chairman of Analog Devices stated,
"in a nutshell, MACSYM happened right before the emergence of the IBM PC, which rendered
the concept obsolete and killed it. It's that simple." On the surface, it appears that
MACSYM’s story was that simple. However, after close analysis, it should be clear that the
story was more complex than Stata’s nutshell description.

The MACSYM II entered the MACSYM product line into Phase I of the Cycle of Technology Disruption. MACSYM II was meant to serve the mid-level measurement and control systems market that was mostly occupied by minicomputer solutions at that time. The targeted customers of that market were laboratory and research institutions who demanded high data acquisition and signal processing capability. MACSYM moved along that dimension, and started its path as a sustaining technology in that market.

In 1981, the IBM PC XT – the technology that would eventually disrupt MACSYM’s market – hit the computer market with full force and began Phase II of the cycle. Its acceptance grew with amazing rapidity, and quickly standardized the personal computer market. Myriads of third-party hardware and software features became available for the PC, and it loomed as a potential threat to the measurement and control systems market.

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87 Dennis Lonigro interview
88 Interview with Ray Stata, November 15, 2000
By 1984, available hardware and software extensions to the IBM PC could combine to allow the PC to perform MACSYM’s functions. The PC solutions did not compare well with MACSYM in data acquisition and signal processing capability – the mainstream dimension of the market segment – but it offered much lower costs and a colossal base of features made possible by third-party extensions. It slowly redefined the mainstream dimensions of the mid-level measurement and control systems market to value and features. ADI attempted some responses to the new dimensions, but eventually failed to survive.

The history of MACSYM’s disruption reveals a frightening aspect of disruptive technology – that is, it can potentially disrupt multiple seemingly unrelated markets. IBM PC originally rose in the personal computing market. As Christensen’s “northeastern pull” suggests, the PC manufacturers targeted the higher-margin segment of the computing market. Thus, the PC soon disrupted the minicomputer market and dominated laboratories and corporate offices. However, the disruption did not end here. Third-party extensions to the PC enabled it to penetrate into an apparently separate market of measurement and control systems and disrupt it. It serves to show that as a technology becomes more powerful, it may kill other technologies that it never intends to attack.

No technology can remain disruptive forever, however. Regardless of how powerful it is, as it becomes a sustaining technology, it enters the first phase of the Cycle of Technology Disruption. The IBM PC, after causing multiple disruptions, is now in the cycle,
and may soon face threats from other disruptive technologies. Nonetheless, the future of the PC is not complete gloom. Even though MACSYM was wiped out rather quickly by the IBM PC solutions, it did react with various defensive strategies. MACSYM failed in its survival endeavors, but other sustaining technologies may face better fortune and endure in the Cycle of Technology Disruption.
8. Acknowledgements

We would like to thank the many people who were willing to “walk down memory lane” with us, sharing their experiences and answering our many questions about the MACSYM product line within Analog Devices. Special thanks go to C. Forbes Dewey, Jr., Barbara Kagan, Jay Kelly, Tom Kelly, Dennis Lonigro, Jack Memishian, Ben Rogers, Bill Schweber, Ray Stata, Catherine Stevens, and Ivar Wold.

We would also like to thank those who rummaged through their attics for related materials. In particular, we thank Tom Kelly for making available past issues of Analog Dialogue and a fantastic set of MACSYM-related brochures, Bill Schweber for numerous MCDigest and Macsymizer issues, Catherine Stevens for News Circuit newsletters and MACSYM programming manuals, Ben Rogers for donating product catalogs, Cammy O’Brien for brochures and advertisements, Michael Timko for MACSYM spec sheets, and Tom Kelly and Riad Wahby for making accessible to us an actual µMAC 4030/5000 demo briefcase. We also thank Jorge Rafael Nogueras and Didier Bousser for their help in the translation of foreign language materials.

Finally, we would also like to thank our professors, David A. Mindell and George W. Pratt, and our teaching assistant, Eden Miller, for their guidance and feedback regarding this case study.

Table 6 - People Interviewed and Their Position(s) at Some Point in MACSYM History

<table>
<thead>
<tr>
<th>Name</th>
<th>Position Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ray Stata</td>
<td>Cofounder, chairman and president of ADI</td>
</tr>
<tr>
<td>Ivar Wold</td>
<td>Director of MCP (originally the SDG)</td>
</tr>
<tr>
<td>Barbara Kagan</td>
<td>Administrative Assistant to Ivar Wold, MCP</td>
</tr>
<tr>
<td>Jay Kelly</td>
<td>Engineering Technician, also Manager of Drafting Group, MCP</td>
</tr>
<tr>
<td>Dennis Lonigro</td>
<td>Hardware Engineer, also Director of Engineering, MCP</td>
</tr>
<tr>
<td>Bill Schweber</td>
<td>Applications Engineer, and Product Marketing Engineer, MCP</td>
</tr>
<tr>
<td>Catherine Stevens</td>
<td>Software Engineer, MCP</td>
</tr>
<tr>
<td>Ben Rogers</td>
<td>Software Engineer, also in Test, Test Methods, Field Service, MCP</td>
</tr>
<tr>
<td>Tom Kelly</td>
<td>Hardware Design Engineer, MCP</td>
</tr>
<tr>
<td>Jack Memishian</td>
<td>Hardware Design Engineer in a group tangentially involved with the MCP</td>
</tr>
<tr>
<td>C. Forbes Dewey, Jr.</td>
<td>Founder of Massachusetts Computing (1978), another firm in the data acquisition business, MIT professor</td>
</tr>
</tbody>
</table>
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